Ductility evaluation of steel frames using semi-rigid connections

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Abstract

Ductility is very essential and lifesaving parameter in profession of earthquake-proof structure design. Non-linear seismic response analysis of steel frames with rigid and semi-rigid connections are evaluated in terms of ductility. This paper includes the seismic behavior and inelastic response of steel moment resisting frames in order to evaluate ductility on the basis of the Indian code of practice. The inelastic behavior of the three-dimensional frames under response spectrum analysis, has been studied. A typical 5-bay frame with five stories have adopted with rigid and semi-rigid connections and by performing dynamic and non-linear static analysis, story and global ductility are evaluated. Definitions of story and global ductility for steel frame are proposed in this paper.

Keywords: *Ductility, story ductility, global ductility, dynamic analysis, pushover analysis, rigid connections, semi-rigid connections.*

INTRODUCTION

The damage to the steel structure caused by earthquakes always force to reevaluate issues related to seismic design of steel structures. The evaluation of inelastic deformation of a structure subjected to strong motion earthquake is difficult process. For this purpose ductility parameter can be used. A ductility parameter can also be used to evaluate the maximum inelastic deformation of a steel structure. It is noticed that there is no unique definition of ductility. In this research paper appropriate definitions of storey ductility and global ductility are proposed.

In this study the presence of rigid and semi-rigid connections on the structural response at a same time is also addressed along with only rigid and only semi-rigid connections. The effect of semi-rigid and composite connections on the nonlinear seismic response of steel frames is evaluated. For this purpose, first the structural responses in terms of maximum top lateral displacements of three steel frames are calculated considering all of the frame connections to be of rigid type. Then the structural responses are evaluated for the frames with semi-rigid connections and finally for the frames with rigid and semi-rigid connections both. Results are compared for the three different cases.

In this paper a typical three-dimensional steel frame with 5-bay and five number of stories is analyzed by using rigid and semi-rigid types of connections. According to the storey and global ductility definitions, dynamic and non-linear static analysis of frames are required to perform. In accordance to this first of all a five storey steel frame is modeled, analyzed by dynamic analysis method (response spectrum analysis) and designed as per Indian code of practice. After that non-linear analysis (static pushover) of the model is performed. From these analysis storey and global ductility are found out for all model steel frames and results are compared.

RELATED STUDY

In past ductility of two-dimensional frames is studied mostly. In this research ductility of a three-dimensional frame is studied, which makes this research work special.

A. Haldar and R. Salazar [1] discussed about several definitions of local and global ductility for two-dimensional frames with semi-rigid connections. They considered maximum inter-storey lateral displacement and absolute lateral displacement when the formation of first plastic hinge as defining parameters for different storey steel frames.

M. Kia and M. Yahyai [2] provided a local and global ductility definitions for two-dimensional frames only, which are adopted for this research. They performed dynamic analysis of frame model with time history analysis whereas here response spectrum analysis is performed. They performed static pushover analysis to find yield displacement of storey and structure.

MODAL ANALYSIS

Steel moment resisting three-dimensional frames of 5-bay with five number of stories are taken for the study. In all the frames, the stories are 3 meters high, 5 meters wide and bays length is 5 meters. All frames are having static seismic and dynamic loading along with dead load and live load of 3 KN/m on stories and 2 KN/m on roof.

Elevation of model frame is as shown in figure below:

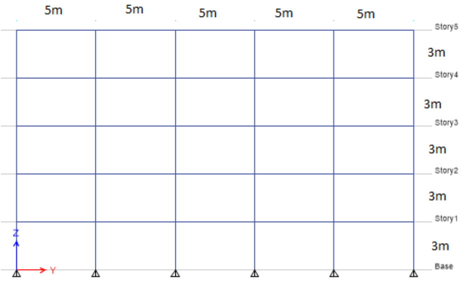

Fig.1: *Elevation of Modal Frame*

Here total five frames with same configurations except the connection types are modeled. The frames are differ in following manner.

Frame 1: frame with all rigid connections

Frame 2: frame with all semi-rigid connections with rigidity factor 0.80

Frame 3: frame with semi-rigid connections with rigidity factor 0.80

Frame 4: frame with all semi-rigid connections with rigidity factor 0.70

Frame 5: frame with semi-rigid connections with rigidity factor 0.70

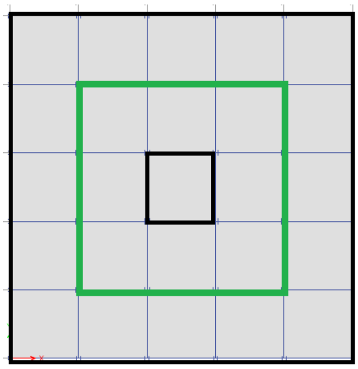

Fig.2: *Plan of Modal Frame*

Frame 3 and 5 are modeled accordingly as shown in above figure where outer and internal frames are with rigid connections and middle frame with semi-rigid connections.

These frame models are analyzed in ETABS 2016. Dynamic analysis with response spectrum method and static pushover analysis are performed in ETABS 2016**.**

Steel sections and connection details

The above said frames are designed as per dynamic loading analysis and the design code used is IS800:2000.

The sections which are used are standard American steel sections.

All frames are provided same steel sections as shown in following table:

Table 1: *Steel Sections used in Modal Frame*

Description	Section detail
Exterior columns	W10*77
Interior columns	W14*120
All beam section	W14*22

For Beam to column joint connection moment connections are provided in all steel frame structures.

Semi-rigid connections and rigid connection which are provided are as Fixed End Plate connections or beam column moment major and minor axis connections. The plate thickness is 12.5 mm.
The specifications of FEP connections in major and minor axis are as shown in figures below:

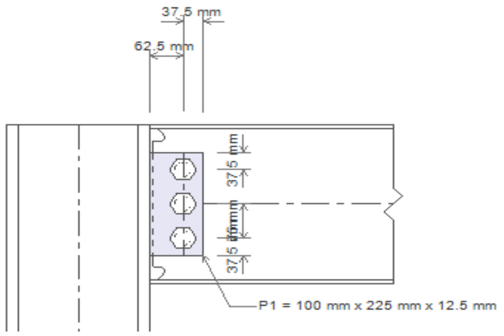

Fig.3: *Beam column major axis moment connection*

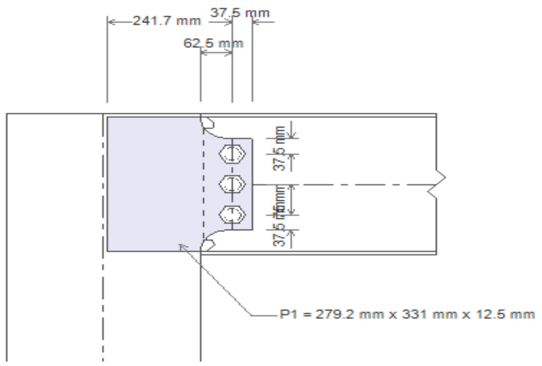

Fig.4: *Beam column minor axis moment connection*

Ductility definitions
Determination of local and global ductility are according to following definitions.

$$\mu_L = D_{max} / d_y$$

In which µL is the local ductility, Dmax is the maximum displacement of the storey which has been obtained under different records, and dy is the corresponding yield displacement of the storey.

To determine the global ductility following equation has been used.

$$\mu_G = D_{max} / d_y$$

In which µG is the global ductility, Dmax is the maximum displacement of the structure (roof), and Dy is the yield displacement of the whole structure.

Problem solution

In three-dimensional frame to evaluate ductility, governing lateral direction needs to be identified. Here frame 1 is analyzed and static pushover curves are obtained for both lateral directions, X and Y. From both the curved structure fails in X-direction while it is safe in Y-direction for full value of monitored displacement.

Here the plan, loading and other specifications are symmetric about both the axis except the steel columns orientation. This is because of the orientation of steel columns causes change in center of stiffness and accordingly static pushover curves for both the lateral directions are different.

For frame 1 nonlinear static analysis is performed in ETABS 2016 and for both lateral directions pushover curves are obtained which are shown in figure below.

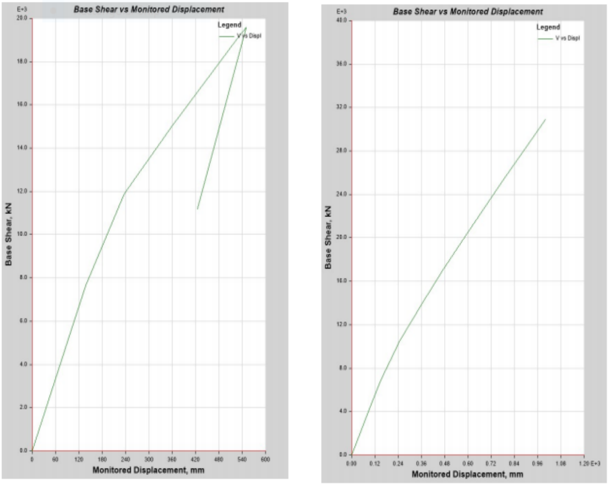

Fig.5: *Static Push Over Curve for Push in X and Y Direction Respectively*

RESULTS

After the dynamic and non-linear static analysis from the given ductility definitions following results are obtained.

Local or storey ductility

Table 2: *Local or storey ductility of Modal Frame*

Storey number	Storey ductility				
	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	2.93	7.96	7.99	7.74	7.71
2	3.89	3.21	3.93	3.87	3.89
3	1.95	2.00	1.99	2.00	2.60
4	1.20	1.21	1.32	1.30	1.33
5	1.00	0.98	0.98	0.97	0.99

Global Ductility

Table 3: *Global ductility of Modal Frame*

Model	Global ductility
Frame 1	1.92
Frame 2	2.26
Frame 3	1.97
Frame 4	2.39
Frame 5	2.10

Figures

Pushover curves for all frames are shown below:

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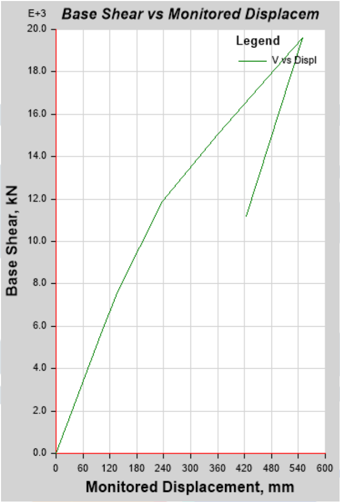

Fig.6: *Pushover curve for frame 1*

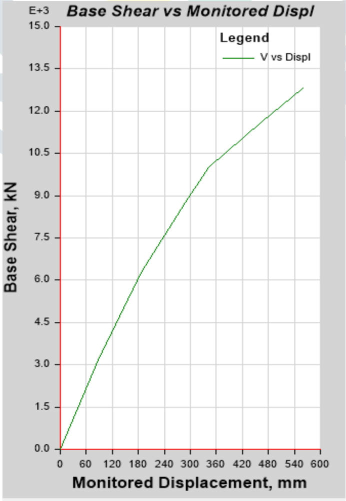

Fig.7: *Pushover curve for frame 2*

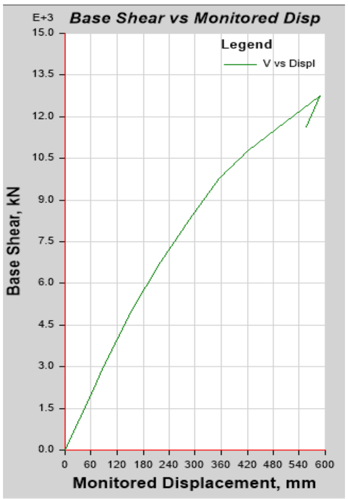

Fig.8: *Pushover curve for frame 3*

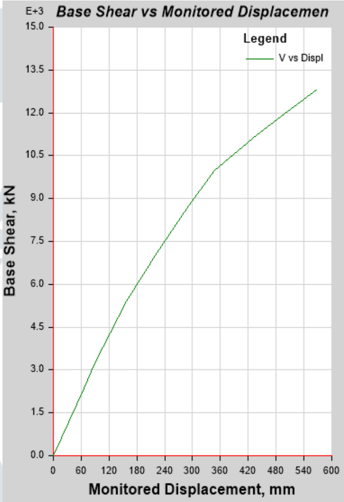

Fig.9: *Pushover curve for frame 4*

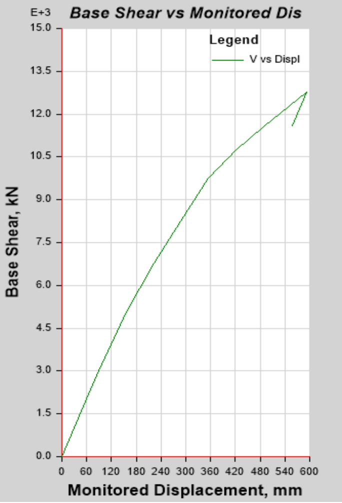

Fig.10: *Pushover curve for frame 5*

CONCLUSION

In steel frame with semi-rigid connections, lateral displacement of structure increases and storey (local) and global ductility of structure also increases. The proper use of semi-rigid connections along with rigid connections provides a good ductile behavior of structure than the use of only either of them.

The combination in which the outer frame is having full rigid connections and middle and inner frames having semi-rigid connections provide higher storey ductility. With the use of semi-rigid connections ductility of lower stories are increasing very significantly.

With the use of semi-rigid connections in steel structure the design steel weight will reduce than using rigid connections. In steel structures steel column orientation plays an important role for evaluation of ductility to find out particular lateral direction for the more adequate values for storey and global ductility.

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